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Measuring the Length of Coarse Woody Debris

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INTRODUCTION

Coarse woody debris[1] (CWD) is an important structural component in forested ecosystems. CWD provides critical habitat for a myriad of organisms, many of which are connected by "functional pathways that are partially or completely unknown" (Torgersen and Bull 1995). Organisms linked to CWD include invertebrates, fungi organisms, many species of plants, especially bryophytes and lichens, and vertebrates (Maser and Trappe 1984; Harmon et al. 1986; Caza 1993; Bull et al. 1997). In addition, the amount, structure, and dynamics of CWD in forests can influence nutrient cycling and productivity, stabilize the soil resource, contribute to global carbon storage, and provide biological legacies—all of which are structural and functional links between present and future forests (Hansen et al. 1991; Harmon and Chen 1991).

Reasons for including length in a CWD survey are varied. CWD length may be part of studies that:

• include the dimensions of CWD as a component of stand structural diversity (Davis et al. in preparation),

• document changes in CWD structural attributes associated with harvesting (Torgersen in preparation; Davis et al. in preparation; Lloyd 2001); or

• examine the relationship between CWD attributes and habitat requirements for specific organisms (e.g., black bear, see Davis 1996; pileated woodpeckers, see Hartwig 1999 and Bull and Holthausen 1993; and carpenter ants, see Torgersen and Bull 1995).

From a structural perspective, a piece of CWD is best described when both large-end diameter and length descriptors are provided—in much the same manner that diameter at breast height and height are used to describe the dimensions of a tree. Large-end diameter and length provide visual descriptors of a CWD piece that can be easily conveyed to others, e.g., ecologists and operational field staff. These dimensions can also be tied to the more common descriptors of CWD used in the literature, e.g., volume/ha.

The operational application of CWD dimensions is demonstrated in various CWD retention guidelines in the United States. For example,

> For mixed conifer stands east of the Cascade Range, the Eastside Forest Plan Amendment stipulates 15 to 20 logs per acre, 6 or more feet long, with a total linear length of 100 to 140 feet of logs 12 inches or greater in small end diameter.
> —*Regional Forester's Decision Notice to Adopt Eastside Forest Plan Amendment No. 2 (USDA 1995 cited in Bull et al. 1997)*

> For western Oregon and Washington north of and including the Willamette National Forest and the Eugene BLM District, leave 240 linear feet of logs per acre greater than or equal to 20 inches in diameter. Logs less than 20 feet in length cannot be credited toward this total.
> —*USDA 1994*

Various methods can be used to sample CWD pieces, including line intersect sampling (LIS), fixed-area plots (circular or rectangular), and strip

[1] In British Columbia, CWD is commonly defined as non-self-supporting, dead, woody, material that is located above the soil and is in various stages of decomposition, including above-ground logs and large fallen branches (BCMOF 2000c). No distinction is made between dead, down wood with roots (i.e., windthrow), and dead, down wood without roots, although the former is a challenge to measure.

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plots (Bate et al. 2001; Harmon and Sexton 1996; Delisle et al. 1988; McRae et al. 1979; van Wagner 1968). Any of these sampling methods may require that length measurements be made, in order to estimate certain CWD attributes. In British Columbia, LIS is a commonly used sampling method because of its historical use in fuel-loading assessments (Trowbridge et al. 1986; Taylor 1997). Piece length is not required for estimating volume/ha or biomass/ha. However, piece length is required if the study is to provide an estimate of piece count on an area basis (e.g., number of pieces/ha or number of pieces/ha by diameter class) or length as an attribute (e.g., average length of pieces, number of pieces/ha by length class, volume/ha by length class).[2,3]

While piece length may appear straightforward at first glance, it can be problematic to define, due to the wide range in piece shapes encountered in the forest. Clear rules governing the measurement of length are necessary to ensure measurement standards are applied consistently within a sampling project. Further, the addition of piece length as a measurement can noticeably increase the sampling time in situations where diameter is measured only at the transect. However, where large- and/or small-end diameters are measured, the addition of a length measurement will not likely add much to the sampling time. The surveyor must keep the project objectives clearly in mind when considering whether to include piece length as a field measurement.

This document suggests approaches for defining the total length of CWD in relation to minimum diameter, multiple segments, broken ends, crooked and curved pieces, branched and forked pieces, and windfalls. The discussion elaborates on some of the basic measurement information provided in the *Field Manual for Describing Terrestrial Ecosystems* (BCMOE 1998), *Provincial Logging Residue and Waste Measurement Procedures Manual* (BCMOF 2000a) and Marshall et al. (2000). A simple worked example showing how to use LIS to estimate the number of CWD pieces/ha is provided in Marshall et al. (2000).

It is not the intent of this document to develop a set of rules appropriate to all situations, but rather to illustrate some issues that must be considered if piece length is to be measured in a CWD sample. Deviations from the approaches presented here may be advantageous in some situations; however, a firm set of rules must be applied to the whole sampling project to ensure overall consistency of measurements.

POINTS TO CONSIDER WHEN MEASURING THE LENGTH OF CWD PIECES

The following discussion applies specifically to the LIS methodology. However, many of the points below apply to other sampling methodologies as well.

When using LIS to sample CWD, piece length should be measured along the center axis[4] of the piece, regardless of the piece shape. The following points apply only to tree boles or branches where the transect line crosses the center axis. If root-wad attributes are of interest, then sampling rules specific to this stratum will need to be developed (e.g., fixed-area plots). Similarly, specific rules may need to be developed in the case of odd-shaped pieces, i.e., slabs.

Minimum Diameter and Total Length (Figure 1)

Measure total length of the piece from the large-end diameter to the minimum diameter[5] of interest, e.g., 10 cm (Figure 1). If a piece is crossed at a point where the diameter is less than the minimum diameter, the piece is ignored.

Rationale: CWD is defined to a minimum diameter, e.g., 10 cm. To be consistent with this definition, the CWD piece is "pencil bucked"[6] at the minimum diameter. The section below the minimum diameter is not tallied if crossed, nor included in the length measurement.

Multiple Segments (Figures 2 and 3)

In the case of a broken piece, consider segments as one piece if the segments are touching or separated by a distance less than the diameter at the point of break.[7] Record the cumulative length of the pieces, not including the space between them.

The center axis of the segment must be crossed by the transect line in order for the piece to be sampled (transect line A, Figure 2). In the case of transect line A, segments 1 and 2 are considered one piece for the purpose of length and diameter measurements. If the segments are separated by more than the diameter at the point of break, then the segments are treated as separate entities and the length recorded only for the segment crossed by the transect line (transect line B, Figure 2). When the transect line crosses at a break, regardless of the distance between segments, the piece is not counted because the center axis of the piece is not crossed (transect line C, Figure 2). The above rules apply whether the piece is segmented (Figure 2) or partially crushed (such that the diameter is less than the minimum) (Figure 3).

Segments of a piece may not be aligned in a row as indicated in the figures. However, the above applies even if the segments are at right angles to each other. It is essential that the surveyor errs on the side of caution and considers the segments as separate pieces if there is any doubt as to the common origin of the segments.

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[2] In the absence of piece length, a count estimate (e.g., count/m of transect) can be derived for comparison purposes, e.g., between treatments. However, a density estimate on an area basis cannot be compiled because the probability that a piece will be crossed depends upon the piece length.

[3] Longer pieces are more likely to be crossed by the line transect than are shorter pieces; the longer the piece crossed by the transect line the fewer pieces/ha represented by that piece length. The length of each piece crossed needs to be known in order to determine the probability associated with selecting each piece, and in turn, to determine the number of pieces/ha that each selected piece represents. An estimate of the number of pieces/ha associated with any given line transect can be achieved by summing the numbers of pieces/ha associated with every piece that is crossed by the line transect. The mean number of CWD pieces/ha for a given area is simply the average of the estimates from each of the line transects established in that area.

[4] The center axis is an imaginary axis that represents the original pith of the piece. It is used only to determine the point of transect crossing and the length dimension of the piece.

[5] CWD is normally defined as being greater than some minimum diameter. This diameter is commonly 10 cm in British Columbia (FPC 2001), but it will vary among jurisdictions and applications. To ensure consistency between CWD piece length and the volume of the CWD piece, generally the length is measured only from the large-end diameter to a point where the diameter equals the minimum.

[6] Pencil bucking is the imaginary separation of a connected piece into two segments. Dr. Torolf R. Torgersen, Chief Research Entomologist, Pacific Northwest Research Station Forestry and Range Sciences Laboratory, Forest Service, USDA, La Grande, Oregon; personal communication, September 2001.

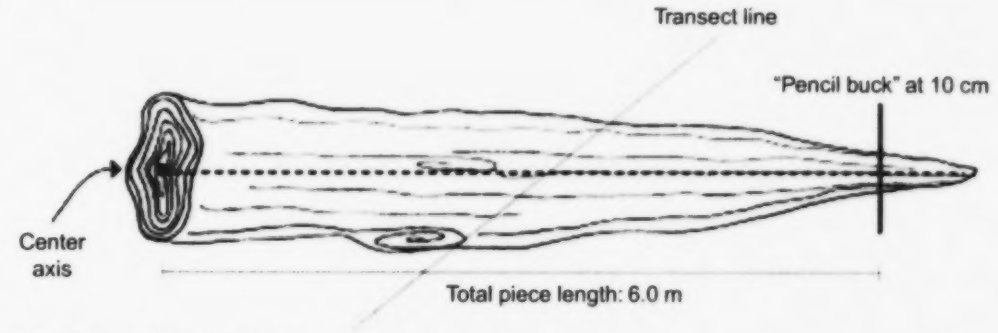

Figure 1. Defining total CWD length.

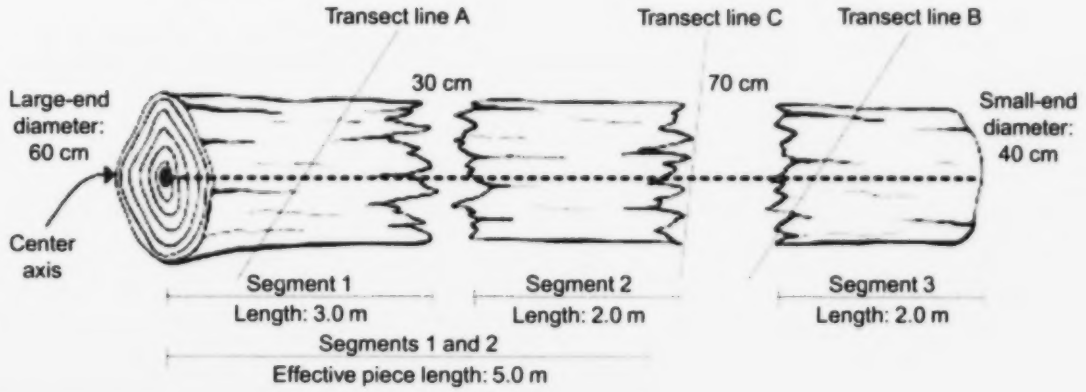

Figure 2. Measuring CWD length when there are multiple segments.

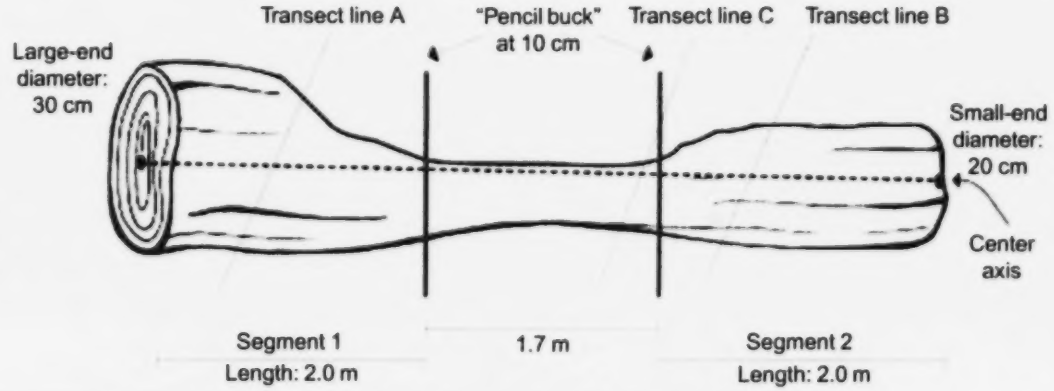

Figure 3. Measuring length when the diameter of a CWD segment is less than the minimum.

Rationale: There are various rules currently used to define a "piece" versus a "log" with multiple breaks. In operational inventories in British Columbia, two approaches are used to address the issue of breakage. In a BC Ministry of Forests' operational cruise, a windfall (roots attached and dbh within the plot) with breakage is treated as a single entity, provided the individual segments are linear and clearly identifiable as originating from the same tree.[8] A similar approach is taken in the BC Ministry of Forests' residue and waste survey procedures for machine breakage.[9] Under the BC Ministry of Forests' *Vegetation Resources Inventory Ground Sampling Procedures* (2000b), adjacent broken pieces are measured as one piece only if the segments are physically attached such that if one part is moved the next part will move.

The approach described under "Multiple Segments" has been used in the United States[10] and is recommended for inventories of CWD structure because:

i) it ties the distance between segments to segment diameter, which provides a proportional basis for comparisons among pieces,

ii) it provides a measure of effective piece length, and

iii) it provides a clear definition of length which can be implemented in the field.

In other applications it may be necessary to reconsider the above approach for multiple segments. For example, in assessing the role of CWD as habitat, the distance rule may need to better reflect the species under consideration. In such cases, the rules governing multiple segments need to be clearly defined to ensure consistency in data collection.

Broken Ends (Figure 4)

Broken ends can be dealt with in either of two ways.

1. Folded (effective) length.

For pieces of CWD with shattered ends, "visually fold in" the broken shards (after "pencil bucking" to the minimum small-end diameter, e.g., 10 cm) so that all voids are filled. Measure the length to the estimated fold. The specific steps given below correspond to Figure 4.

Step 1: Locate the minimum small-end diameter.

Step 2: Locate the XY line upon which the volume above the minimum small-end diameter to the XY line (Area B) equals to the void of the missing wood (Area A).

Step 3: Record the length, which is measured from the large-end diameter to the XY line (BCMOF 2000a).

In this approach, a piece is selected for measurement only if the transect line crosses the piece between the large end and the XY axis (e.g., transect lines A and B). If the area affected by folding is crossed, the diameter that should be recorded at the point where the transect crosses the center axis of the piece is the effective diameter after the folding has occurred. The piece crossed by transect line C is not recorded because the section of the piece crossed by the transect line is used to backfill area A.

2. Actual length.

For pieces with shattered ends, measure piece length to the minimum diameter (Figure 4). In this approach the diameter perpendicular to the transect is recorded at the point of

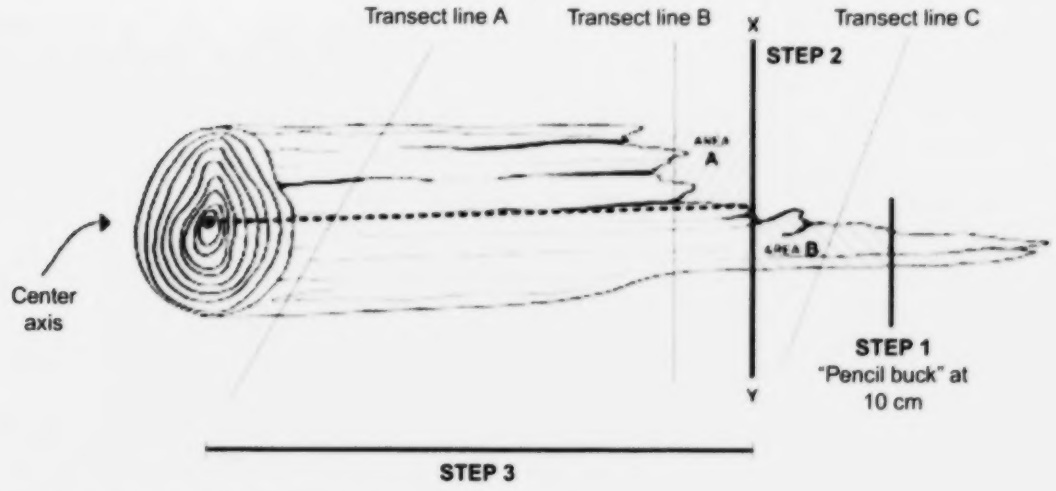

Figure 4. Defining length of CWD pieces with a broken ends.

[8] Bruce Marskstrom, Cruising and Waste Technician, Vancouver Forest Region, BC Ministry of Forests, Nanaimo, BC; personal communication, September 2001.
[9] See Footnote 8. [10] See Footnote 7.

crossing and total length is measured from the large end to the minimum small-end diameter (e.g., 10 cm). The piece crossed by line transect C would be measured according to this definition of length.

Rationale: Both approaches are currently used in operational surveys. The former approach to measuring CWD length is used in BC Ministry of Forests' residue and waste surveys on fixed-area plots (BCMOF 2000a). The latter approach to measuring CWD length is used in the *Field Manual for Describing Terrestrial Ecosystem Mapping* (BCMOE 1998) for LIS plots. Neither approach introduces bias. The former provides a piece length that corresponds to the effective piece that will be used for determining volume or biomass. The latter provides an estimate of the actual piece length. The folded approach to measuring length is advantageous if the small- and large-end diameters are required. The actual length approach may be more appropriately used with LIS transects when only the diameter perpendicular to the point at which the transect crosses the center axis of the piece is recorded. Irrespective of which approach is adopted, it is important that the choice is used consistently throughout a project.

Crooked and Curved Pieces (Figure 5)

Measure the entire piece length from the large end to minimum small-end diameter. In the case of multiple intersections (e.g., intersections A and B, Figure 5), record the entire length of the piece for each intersection.

Rationale: Each intersection is an independent measure. The fact that multiple intersections are possible compensates for the fact that the probability of crossing a crooked piece is less than if the piece were straight because the effective length of the piece is shorter than the true length.

Branched and Forked Pieces (Figures 6 and 7)

If a CWD piece is branched, "pencil buck" the branch at the intersection of the branch and the main bole. If the transect crosses both the bole and branch, then treat them as separate pieces and record the bole and the branch length respectively (Figure 6). If the transect crosses the branch, then record only the branch length.

If a piece is forked, but the diameters of the forks are greater than or equal to the minimum small-end diameter, then select the fork with the largest diameter as the main bole (Figure 7). If the forks have an identical diameter, then designate the longest fork as the main bole (Figure 7). If the forks are identical in diameter and length, then randomly assign one of the forks as the main bole and the other as a "branch".

Rationale: If a piece is branched or forked, a main bole must be chosen. Using relative size (i.e., diameter and length) as the basis for this choice will provide consistency.

Windfall (Figure 8)

In the case of a windfall with attached roots, consider the bole and root wad as two measurement groups. This will improve sampling efficiency and accuracy by removing uncertainty about how to tackle a complex situation. In this document, only bole measurements are considered. Root wads may be sampled using either LIS or some other technique, with appropriate measurements taken on each sampled root wad to estimate the attributes of interest (e.g., volume/ha, biomass/ha).

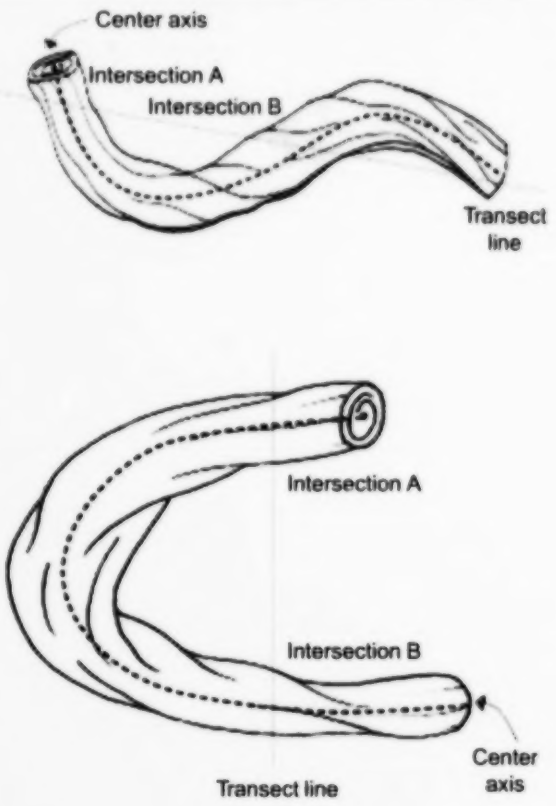

Figure 5. Measuring the length of crooked CWD pieces.

The suggested definitions are as follows:

> Root wad = the volume of wood below the point of germination (POG) or high side, whichever is higher (BCMOF 2000c).
>
> CWD or bole wood = the portion of the tree bole between POG or high side (whichever is higher) and the small end of the piece.

If the transect line crosses the center axis of the tree bole, then record length from either the high side or POG (which ever is higher) to the minimum small-end diameter (transect line A, Figure 8). If the transect line crosses only the center axis of the root wad, then no measurement is recorded unless the root wad is being sampled (transect line B, Figure 8). If both the root wad and bole are crossed by the transect, then each is recorded as a separate entity. If a piece is partially broken at the butt and some roots are still attached, none of the root wad should be used to "fill in" the missing part of the bole.

Rationale: For ease of sampling, tree boles and root wads are defined as separate groups. Due to their different shapes, different measurements and possibly different sampling strategies are required.

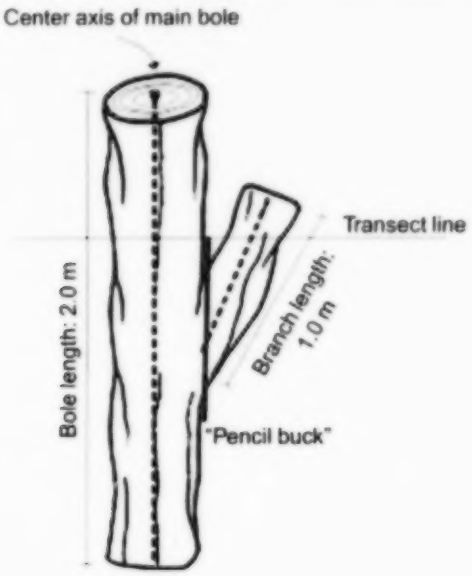

Figure 6. Determining length of a CWD piece where the distinction between the bole and branch is clear.

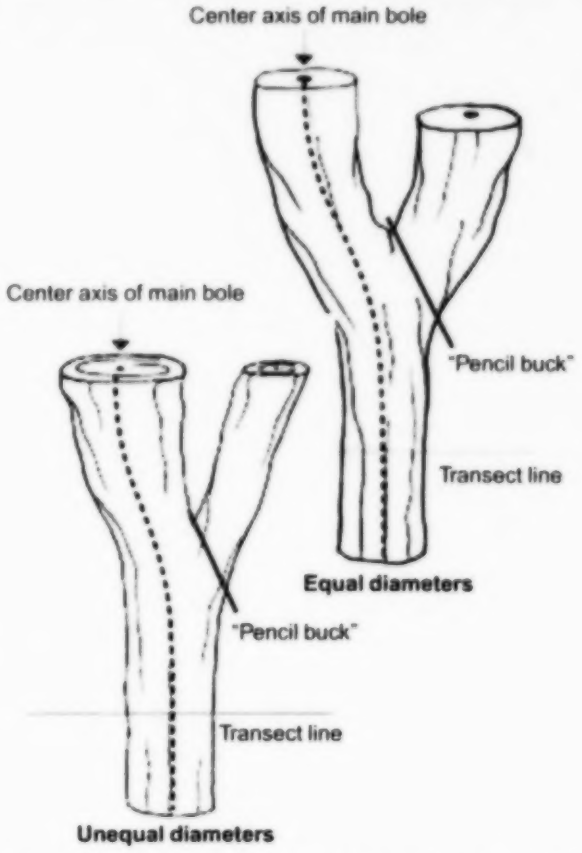

Figure 7. Determining length of a forked piece where the distinction between the bole and branch is not clear.

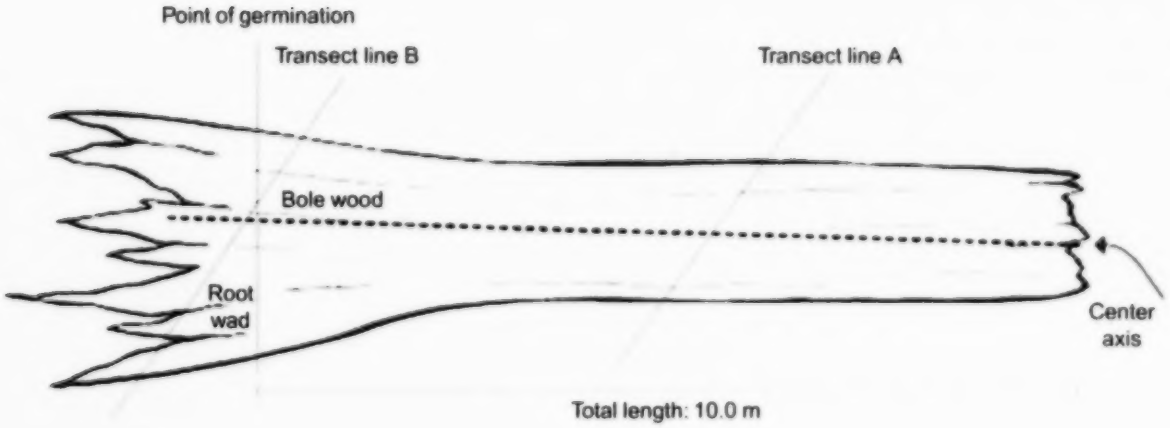

Figure 8. Length of windfalls: root wads and bole wood.

DISCUSSION

Determining the length of dead, down CWD is complex, particularly in the case of pieces with large branches or pieces with no obvious length (e.g., slabs, disks). Some of these complexities are briefly addressed below.

For ease of determining total CWD volume/ha using LIS, large branches are often "pencil bucked". These branches are treated as separate pieces, with individual lengths, diameters, volumes, etc. In the case of total CWD volume/ha, treating branches as individual pieces does not affect the total volume because the volumes are additive. However, in the case of total numbers of pieces, the "pencil bucked" branches are counted as separate pieces, resulting in an elevated total density. For both volume/ha and density summaries by diameter class, "pencil bucking" may result in elevated volumes and densities for the smaller diameter classes and, conversely, lower volumes and densities for the larger diameter classes. The magnitude of the differences will depend on branch frequency and the proportion sampled.

If a researcher is concerned with counting all attached segments as a single piece (e.g., all branches and the stem of a down tree) using LIS, then a piece should be measured only if the center axis of the main piece is crossed by the line transect. The length that should be measured for that piece is the length of the center axis up to the minimum diameter limits for the main piece. The piece volume should reflect the portion of the entire piece (stem and branches) that is greater than the minimum diameter limits. Such a procedure can be complicated and time consuming, initially for determining the center axis of the main piece and subsequently for making all of the measurements necessary to determine total piece volume.

CWD pieces have many shapes ranging from the classic round or semi-round cross sectional log to pieces that are truly non-round in cross section, i.e., slabs. Often these latter shapes do not have an obvious length dimension either because they are too short or because they are circular, e.g., disk shape. If piece length is desired in such cases, it may be helpful to think of the vertical projection of the piece onto a horizontal plane (the so-called footprint of the piece). The longest axis of this footprint would be considered its "length". Alternatively, pieces that have no clear linear dimension may be considered as a separate group, with no length measurements taken, and volume determined as for odd-shaped pieces (Marshall et al. 2000).

Adding piece length measurements to a study can substantially increase the time required to complete measurements at a sample point, depending on the other measurements being made. In many LIS applications, the diameter of each piece at the point of intersection is used to determine the volume of that piece. In such situations, adding a length measurement for each piece will likely increase the sampling time considerably. However, if the large- and/or small-end diameters of each piece are required as part of the sampling protocol, then adding a length measurement will not likely increase the sampling time by very much.

The precision required for the length measurement will also determine the time (and cost) of making this measurement. The objectives of a study, and especially the reasons why piece length is required, should be considered when establishing measurement standards for piece length. The *Field Manual for Describing Terrestrial Ecosystems* (BCMOE 1998) recommends measuring length to the nearest 0.1 m. However, in some cases, it may be sufficient to record length to the nearest metre, or to place pieces into broad length classes. Whatever the length-measurement standards, they should be applied consistently within each sampling project.

CONCLUSIONS

Piece length is an important descriptor of CWD structure. However, whether length needs to be measured depends on the study objectives. If length is required, then strict adherence to a set of rules is needed to ensure measurement consistency. The considerations described in this paper are indicative of those that need to be addressed in defining CWD piece length, and in establishing and applying measurement rules for a sampling project.

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